Quarterly Journal Fides et Ratio
Issue 1(53)2023, ISSN 2082-7067, Pages 112-124

Lifetime physical activity and the cognitive condition of adults. Research of three independent groups of Polish adults

Aktywność fizyczna podejmowana w trakcie życia a kondycja poznawcza osób dorosłych. Badania trzech niezależnych grup dorosłych Polaków[1]

https://doi.org/10.34766/fetr.v53i1.1024

Ewa M. Szepietowska[a], Alicja K. Dąbal[b]

[a] Associate Professor Ewa Małgorzata Szepietowska[1], PhD, https://orcid.org/0000-0003-3383-0353
[b] Alicja Karolina Dąbal[1], MA, https://orcid.org/0000-0002-7010-9699
[1] Institute of Psychology, Maria Curie-Skłodowska University, Poland, Lublin, Department of Clinical Psychology and Neuropsychology

Abstract: One of the typical symptoms of aging is the deterioration of the functioning level in specific cognitive areas. A significant number of research reports suggest that physical activity over the life course may be conducive to maintaining cognitive efficiency in late adulthood and old age. Aim: Research was undertaken to investigate whether the level of the reported physical activity over the life span can determine cognitive performance in the selected areas in adults. Material and methods: The material was collected from 2019. Individuals aged 40+ were invited to participate in the study. Three independent assessments were carried out in separate groups of subjects (Group 1: N = 120; Group 2: N = 90; Group 3: N = 60). A total of 270 individuals participated in the study. A questionnaire designed by the authors was used to assess the intensity of physical activity. The MoCA test, WAIS-R PL subtests, verbal fluency tests, BDI-II and DEX-S were applied to assess cognitive and emotional functions. In Group 3 the Trail Making Test was also used. Results: Linear regression analyses showed significant similarities across groups. Higher age was associated with lower cognitive performance, whereas higher level of physical activity reported by the subjects corresponded to better efficiency in the specific cognitive competencies. Physical activity was the main determinant of cognitive performance in the youngest study group (aged between 45 and 60 years). Conclusions: Older age promotes cognitive decline. Higher level of the reported lifetime physical activity positively affects cognitive functioning at later stages of life. Physical activity may play a compensatory role and support cognitive competencies in older adults, especially in operations involving executive functions. However, the relation between physical activity and cognitive performance varies depending on the age of the subjects. The older a person gets, the more important the age factor becomes for the level of cognitive functioning, and the observed impact of physical activity decreases.
Keywords: ageing, cognitive functioning, physical activity

Abstrakt: Jednym z typowych objawów starzenia się organizmu jest spadek poziomu funkcjonowania w wybranych obszarach poznawczych. Znacząca liczba doniesień wskazuje, że aktywność fizyczna podejmowana w kolejnych latach życia może sprzyjać podtrzymaniu kondycji poznawczej w okresie późnej dorosłości i starości. Cel: Podjęto badania mające na celu określenie, czy nasilenie deklarowanej aktywności fizycznej podejmowanej na przestrzeni życia może determinować sprawność poznawczą w wybranych jej obszarach u osób dorosłych. Materiał i metody: Materiał gromadzono od 2019 roku. Do badań zapraszano osoby w wieku 40+. Zrealizowano trzy niezależne badania w odrębnych grupach osób (grupa 1: N = 120; grupa 2: N = 90; grupa 3: N = 60). Łącznie w badaniach wzięło udział 270 osób. Do oceny nasilenia aktywności fizycznej wykorzystano autorski kwestionariusz; do oceny funkcji poznawczych i emocjonalnych: test MoCA, podtesty WAIS-R PL, testy fluencji słownej, BDI-II oraz DEX-S. W grupie 3 wykorzystano także Test Łączenia Punktów. Wyniki: Analizy regresji liniowej wykazały znaczące podobieństwa w grupach. Wyższy wiek wiązał się z obniżeniem sprawności poznawczych, natomiast wyższe nasilenie aktywności fizycznej raportowanej przez badanych determinowało lepszą sprawność wybranych kompetencji poznawczych. Aktywność fizyczna była głównym determinantem sprawności poznawczej dla osób najmłodszych spośród badanych, będących w wieku pomiędzy 45. a 60. rokiem życia. Wnioski: Starszy wiek sprzyja osłabieniu kondycji poznawczej. Wyższe nasilenie raportowanej aktywności fizycznej podejmowanej w trakcie życia pozytywnie kształtuje sprawność poznawczą na kolejnych etapach życia. Aktywność fizyczna może pełnić funkcję kompensacyjną i wspomagać kompetencje poznawcze u osób starszych, szczególnie w przypadku działań angażujących funkcje wykonawcze. Związek aktywności ruchowej i sprawności kognitywnych kształtuje się jednak w zróżnicowany sposób w zależności od wieku badanych. Im osoba jest starsza, tym istotniejszy dla poziomu funkcjonowania poznawczego staje się czynnik wieku, a obserwowany wpływ aktywności fizycznej maleje.
Słowa kluczowe: aktywność fizyczna, funkcjonowanie poznawcze, starzenie się

1 Artykuł w języku polskim: https://www.stowarzyszeniefidesetratio.pl/fer/2023-1Szep.pdf

Introduction

As populations age, more and more importance is attached to possible ways of maintaining cognitive well-being in late adulthood. The process of physiological (normal) aging is associated with increasing difficulties in executive functioning, attention divisibility, psychomotor speed, as well as episodic and procedural memory (Oschwald et al., 2020). Age is also a risk factor for dementia (Krivanek, Gale, McFeeley, Nicastri, Daffner, 2021). A wealth of available evidence supports the belief that regular physical activity is associated with volumetric and functional changes in the brain that promote overall cognitive performance (Barnes, 2015) and its various dimensions in older adults (Ingold, Tulliani, Chan, Liu, 2020). Physical activity also modifies the negative impact on cognitive function produced by cardiovascular and metabolic disorders (hypertension, diabetes, obesity) and other conditions (osteoporosis, depression) (Busse, Gil, Santarém, Filho, 2009). Despite the controversies concerning the methodology which should be used to investigate the relationship between physical activity and cognitive performance in late life, it is this type of activity that has been recommended by various organisations as a way to keep up the existing capacities or to alleviate age-specific cognitive deficits (Krivanek et al., 2021).

Physical activity can favourably affect brain development and cognitive functioning from an early age, although the existing evidence suggesting benefits of exercise in the youngest subjects is inconclusive. A meta-analysis by Singh and colleagues (2019) showed that beneficial effects of physical exercise were found in children and adolescents by 10 out of 21 (48%) of the research reports taken into account. Greeff, Bosker, Oosterlaan, Visscher and Hartman (2018) observed that the positive effects of physical activity in children aged 6-12 years are particularly evident in executive function, attention and academic performance. Higher academic achievement is closely linked to better executive functioning, as executive functions are of great importance for success in school and for the emotional development of children and adolescents (Bidzan-Bluma, Lipowska, 2018).

Longitudinal studies found positive delayed effects of physical activity (regardless of its form) reflected by reduced risk of cognitive deficits and dementia. Some evidence showed a protective role of this type of activity regardless of the life stage at which it was performed (Green, Lee, Thuret, 2019). In contrast, other reports have suggested that important determinants of positive ageing include physical activity during adulthood, but not during childhood and adolescence (Reas et al., 2019). Other research reports have indicated that the baseline activity level and physical status of people aged 55+, even 6-8 years after the first measurement, are good predictors of the level of cognitive functioning and show a protective effect against age-related decline (Barnes, Yaffe, Satariano, Tager, 2003; Yaffe, Barnes, Nevitt, Lui, Covinsky, 2001). The magnitude of the protective effect depends on the amount of physical activity people engage in, and ranges from 26% for moderate levels of physical activity compared to no or low levels of physical activity (Guure, Ibrahim, Adam, Said, 2017), to 38% in those engaging in high levels of physical activity (Sofi et al., 2011).

We can also expect positive effects of past activity in the future, even after a decade of life. Rovio and co-authors (2005) showed that a lower risk of dementia at 65-79 years of age was observed in individuals who exercised at least twice a week at midlife. A meta-analysis performed by Hamer and Chida (2009), taking into account data from studies involving a total of 163,797 subjects, as well as meta-analyses of 719 articles investigating effects of physical activity on cognitive capacity in individuals aged 55+ years (Klimova, Dostalova, 2020), confirmed a positive impact of broadly understood physical activity on participants' cognitive performance, particularly in the domains of attention, verbal memory and episodic memory. Importantly, this effect was demonstrated in all the reports included in the meta-analysis, regardless of the research methodology applied. Better verbal memory and psychomotor speed at 43-55 years of age is clearly associated with better cardiorespiratory endurance 25 years earlier (Zhu et al., 2014). Low level of physical activity and excessive amount of time spent watching

TV (sedentary lifestyle) in youth to mid-adulthood are associated with poorer performance on cognitive tasks in mid-life (with lower speed of information processing and deficits in executive function, but not in verbal memory). Compared to subjects who spent little time watching TV and often engaged in physical activity, the likelihood of poor cognitive performance was almost twice as high in adults who watched TV a lot and rarely engaged in physical activity (Hoang et al., 2016).

However, the strength of the beneficial effect of exercise may diminish over time, and an important role in supporting cognitive functioning may be played by continued involvement in physical activity. Richards, Hardy and Wadsworth (2003) showed that, although engagement in physical activity at 36 years of age is associated with slower memory decline between 43 and 53 years of age, those who continued to be physically active at 43 years of age had better memory at 53 years of age than the subjects who had stopped exercising at this stage of life. Related evidence was also reported by Middleton, Barnes, Lui and Yaffe (2010) who carried out a study involving 9,344 females aged 65+ years. The participants rated their physical activity during adolescence, at the age of 30, at the age of 50 and in late life. Cognitive performance was measured using the modified Mini-Mental State Examination (mMMSE). Women who were physically active at any stage of their lives, compared to those who were not active, were less likely to exhibit cognitive impairment in late adulthood. Out of all the periods over the course of life, physical activity during adolescence was most significantly related to the reduced likelihood of cognitive impairment in late life. Furthermore, Dik, Deeg, Visser and Jonker (2003) observed that retrospectively reported regular physical activity at age 15-25 correlated with speed of information processing at an older age (62-85 years). This correlation was not explained by current physical activity or other lifestyle factors, but it was only found in men. At the same time, these researchers found no association between physical activity at young age and overall cognitive functioning, as measured by the MMSE test.

Studies investigating the relationship between physical activity and cognitive functions present certain methodological issues possibly explaining why the findings are inconsistent. The most important problems include: different definitions of physical activity, its nature, frequency and intensity, as well as the lack of longitudinal measurements or their varying duration (Blondell, Hammersley-Mather, Veerman, 2014). The way physical activity is measured also poses certain problems. Researchers most commonly apply self-report questionnaire-based methods because they are inexpensive to use (Innerd et al., 2015). They most commonly focus on activities performed during the preceding seven days. For example, International Physical Activity Questionnaire–IPAQ (Booth, 2000) measures duration of activity related to work, mobility, housework and caring for family, sports and recreation, as well as sedentary activities. Similar in nature is the Global Physical Activity Questionnaire (GPAQ) which was constructed in 2002 under the aegis of the World Health Organisation (WHO) (Bull, Maslin, Armstrong, 2009).

The concerns related to self-reporting techniques arise from the fact that respondents tend to rate their physical activity higher compared to that which is measured with objective methods (Wasilewska, 2017). Other limitations of questionnaire methods have also been pointed out (Finger et al., 2015). These include: difficulty in estimating the time, frequency and intensity of physical activity, sometimes difficulty in distinguishing between physical activity and exercise, problems with recalling facts, or understanding the relationship between physical activity and gender or cultural factors (Booth, 2000). Due to the limitations of self-report instruments, other tools used in addition to these subjective methods enable objective assessment of physical activity, i.e. a pedometer or accelerometer. A study of women aged 50-64, which applied an abridged version of the IPAQ-S questionnaire and an accelerometer, showed poor correlations between the two measures (Bergier et al., 2020). Conversely, a study of 419 healthy adults showed significant correlations between intensity of physical activity assessed subjectively or measured using an accelerometer and mental well-being, depression and pain intensity (Panza, Taylor, Thompson, White, Pescatello, 2019). Aunger and Wagnild (2020) also point out that objective techniques do not take into account the context of physical activity or sedentary lifestyle.

1. Purpose of the study

Three independent studies were carried out in separate groups of people over 40 years of age, in order to investigate whether the level of reported physical activity in which they engaged in the course of life is a determinant for cognitive performance in selected domains. A total of 270 subjects took part in the whole study.

2. Material and methods

The related assessments were carried out from 2019, during individual meetings conducted by two psychologists. Interested persons were invited to participate, while others were recruited using the snowball technique. Three independent studies were performed. The project was approved by the Research Ethics Committee at the UMCS Faculty of Education and Psychology (No. 41/2020). Eligibility criteria for participation were as follows: age 40+, voluntary participation in the study, health status and cognitive capacity making it possible for the subjects to perform cognitive tasks, independence in activities of daily living and a declaration stating a lack of psychiatric conditions. Participants were informed of the scientific purpose of this study and that they could withdraw at any time.

The following tools were used in all the three studies:

Specially designed questionnaire covered demographics and individual data, and asked about physical activity during (a) childhood and at young age, as well as (b) adulthood and at present. Participants were asked to take into account not only typical sports and exercise, but also physical strain related to hobbies or other daily chores (e.g. gardening). The participants' rated their physical activity by selecting the item matching their response. Each item corresponded to a number of points (Likert scale); in part (a) *Very rarely–only in PE classes and during daily routines* = 0 points; *Rarely, usually in PE classes and sometimes outside school (e.g. football, cycling, skating, gardening) and during daily routines* = 1 point; *Not only in PE classes and during daily routines but also outside school, however irregularly* = 2 points; *In PE classes and during daily routines, as well as some additional engagements on a regular basis* = 3 points; *Consistently–not only during PE classes or daily routines but also additional engagements, e.g. in sports clubs (e.g. swimming, running, gardening, etc.)* = 4 points, and in part (b): 0 points = *I do not engage in sports or exercise – physical activity only during daily routines;* 1 point = *Besides daily routines, infrequent and irregular activity (e.g. from time to time taking a walk or gardening)*; 2 points = *Yes, not only daily routines but also additional engagements, but irregularly (e.g. longer walks, jogging, cycling, etc. once a month);* 3 points = *Besides daily routines, some additional engagements on a regular basis (e.g. once a week);* and 4 points = *If possible, I engage consistently (a few times a week), in such activities as walking, swimming, jogging, cycling, etc.* Both in part (a) and in part (b) the participants could score a maximum of 4 points, with a total of 8 points. A higher score reflected frequently and regularly performed physical activity, usually linked with involvement in sports clubs or pursuit of a hobby.

The questionnaire also included questions on gender, education level, place of residence, occupational activity, addictions (No; Yes–nicotine, alcohol, other) and medical conditions (No; Yes–hypertension, diabetes, obesity, neurological diseases e.g. MS, Parkinson's disease).

Assessment of cognitive and emotional functioning was performed using:

a. verbal fluency tasks (five categories: semantic fluency (Animals); phonemic fluency (production of words starting with the letter K; verb–production of words prompted by the following clue: what a person does? and two emotional fluency tasks, involving recall of words coming to mind in response to the clues: Joy and Fear). Each task took one minute to complete, and the analyses took into account the number of correct answers, i.e. words that corresponded to the given category, with no repetitions, neologisms or inflected forms of words. Verbal fluency involves executive functions, language resources, attention, working memory, immediate and semantic memory (Szepietowska, Gawda, 2011).

b. MoCA test (Montreal Cognitive Assessment scale) (Nasreddine et al., 2005). It is a screening tool used to detect cognitive deficits. It assesses short-term memory, visuospatial and executive functions, language, verbal fluency, attention, naming, abstracting and orientation in time and place. Scores in MoCA test are in the range of 0-30 points. A score ≥26 points shows there are no cognitive difficulties (www.mocatest.org).
c. WAIS-R PL subtests: Forward Digit Span, Backward Digit Span, and Vocabulary (Brzeziński et al., 2004). Forward Digit Span subtest assesses the efficiency of attention and immediate (auditory) memory, whereas Backward Digit Span subtest additionally involves working memory, as well as the ability to inhibit the habitual process of memorising and reproducing. The Vocabulary subtest assesses semantic memory, verbal intelligence and language competence. Raw scores were included in the analyses.
d. BDI-II (Beck Depression Inventory) – the Polish version (Łojek, Stańczak, 2019). The tool is designed to assess intensity of depression.
e. Dysexecutive Questionnaire/Self (DEX-S) subtest of Behavioural Assessment of the Dysexecutive Syndrome, BADS). DEX-S is used as a self-report measure to describe the severity of executive difficulties in daily life. It consists of 20 questions relating to various behaviours and situations engaging executive functions. The respondent provides answers corresponding to scores on a Likert scale, ranging from 0 (never) to 4 (very often). A high score (a range of 0–80 points) indicates that the person perceives greater difficulty in performing tasks involving executive functions (Wilson, Alderman, Burgess, Emslie, Evans, 1996).

The third study additionally used the Trail Making Test – part A and B (Lezak, Howieson, Bigler, Tranel, 2012). Part A consists of 25 circles with numbers, and the subject is to connect these following the order of the numbers; Part A measures psychomotor speed, attention and visual scanning. Part B consists of circles with letters and numbers – these are to be connected in line with alternating sequencing (1-A-2-B-3-C, etc.); this task to a greater degree than Part A engages cognitive flexibility. Both parts are to be performed as quickly as possible – time is the measure of performance, however the examiner is to draw the subject's attention to errors (which increases the time). There is no Polish version, however the tool is frequently used in assessing cognitive functions.

Statistical analyses, performed using IBM SPSS v. 25 and 26, included one-way ANOVA for comparison of the independent results in the three groups, with post-hoc tests, and Pearson's $\chi 2$ test of independence, and with Cramer's V test. To assess whether cognitive performance was determined by the level of physical activity, a series of linear regression analyses were performed (separately for each cognitive task and for groups 1-3). Scores in the cognitive tests were regarded as the response variables, whereas age and the total score for physical activity in part (a) and (b) of the questionnaire were defined as explanatory variables (predictors). Age as a predictor was not correlated to the self-reported physical activity (Group 1: $r = -0.13, p = 0.08;$ Group 2: $r = -0.011, p = 0.46;$ Group 3: $r = 0.17 p = 0.09$).

3. Characteristics of the study participants

Group 1. The participants (N = 120) ranged in age between 44 and 84 years (M = 57.42, SD = 10.48). Women were a majority. 60% of the participants reported existing metabolic diseases, including hypertension and diabetes, as well as endocrine disorders. Participants reporting secondary or higher formal education outnumbered those with primary education. The respondents were from urban areas – large cities and small towns (n = 37, i.e., 30.8% in each category) and from rural areas (n = 46; 38.4%). Working individuals constituted more than half of the group. Those with medical conditions reported slightly lower level of physical activity over the course of life (M = 3.41, SD = 2.07), compared to the subjects with good health status (M = 4.15, SD = 2.38; t = 2.017, p = 0.09).

Group 2. The study involved 90 individuals aged 40-81 years (M = 53.04, SD = 8.94). Over half of these were women. More than one in two respondents

Table 1. The characteristics of the three groups

Variables	Group 1 N = 120 n (%)	Group 2 N = 90 n (%)	Group 3 N = 60 n (%)	χ2 (p) Cramer's V
Gender - female - male	 75 (62.5%) 45 (37.5%)	 61 (67.8%) 29 (32.2%)	 46 (76.7%) 14 (23.3%)	 3.66 (p = 0.16)
Chronic medical conditions - yes - no	 72 (60%) 48 (40%)	 42 (46.7%) 48 (53.3%)	 26 (43.3%) 34 (56.7%)	 5.90* (p = 0.052) Cramer's V = 0.15
Level of education - primary - secondary and tertiary	 14 (11.7%) 106 (88.3%)	 26 (28.9%) 64 (71.1%)	 8 (13.3%) 52 (86.7%)	 11.48* (p = 0.03) Cramer's V = 0.21
Employment status - professionally active - pension/ unemployment	 78 (65%) 42 (35%)	 59 (65.5%) 31 (34.5%)	 40 (66.7%) 20 (33.7%)	 0.049 (p = 0.98)
Addiction - yes - no	 32 (26.7%) 88 (73.3%)	 30 (33.3%) 60 (66.7%)	 14 (23.3%) 46 (76.7%)	 2.014 (p = 0.37)

Variables	M (SD)	M (SD)	M (SD)	F (p) and post-hoc comparisons
Level of physical activity	3.71 (2.16)	4.21 (2.20)	4.20 (2.08)	1.764 (p = 0.17)
Age	57.40 (10.48)	53.04 (8.94)	56.84 (9.87)	5.445** (p = 0.005) 1-2 p = 0.005** 1-3 p = 0.93 2-3 p = 0.07
Semantic fluency	20.22 (7.25)	22.11 (6.54)	22.57 (6.63)	3.09 (p = 0.06)
Verb fluency	18.25 (6.59)	18.79 (5.59)	19.38 (5.53)	0.721 (p = 0.49)
Joy fluency	10.87 (4.59)	11.40 (6.53)	10.22 (4.85)	0.874 (p = 0.42)
Fear fluency	9.73 (4.77)	9.71 (4.87)	8.20 (4.22)	2.457 (p = 0.09)
phonemic fluency	17.73 (6.40)	17.77 (4.87)	17.42 (5.12)	0.079 (p = 0.92)
Forward Digit Span	6.09 (1.91)	6.00 (1.81)	6.90 (2.19)	4.503* (p = 0.02) 1-2 p = 0.94 1-3 p = 0.02* 2-3 p = 0.016*
Backward Digit Span	5.41 (2.03)	5.68 (1.79)	6.02 (1.87)	5.68 (p = 0.13)
Vocabulary	41.99 (15.28)	46.21 (14.09)	39.42 (16.22)	3.964* (p = 0.02) 1-2 p = 0.11 1-3 p = 0.53 2-3 p = 0.02*
MoCA (sum)	26.05 (3.54)	27.32 (2.35)	27.17 (2.55)	5.552** (p = 0.004) 1-2 p = 0.006** 1-3 p = 0.04* 2-3 p = 0.96
BDI II	11.04 (8.07)	10.53 (7.39)	10.75 (9.04)	0.104 (p = 0.90)
DEX-S	19.46 (10.65)	23.77 (11.98)	24.00 (11.65)	5.038** (0.007) 1-2 p = 0.02* 1-3 p = 0.03* 2-3 p = 0.99
TMT A (time/sec)	-	-	64.37 (53.95)	-
TMT B (time/sec)	-	-	92.58 (57.46)	-

*p≤0.05; **p≤0.01.

reported secondary or higher education, and represented working population. More than one in three respondents were from urban areas (36.7%, n = 33), and the others lived in large cities (n = 31) or small towns (n = 26). Existing medical conditions, mainly hypertension, was reported by less than half of the respondents. There were no differences in the level of physical activity reported by those with medical problems (M = 4.25, SD = 2.17) and the healthy individuals (M = 4.17, SD = 2.24; t = -0.17, p = 0.86).

Group 3. The final study took into account 60 individuals aged 43-80 years (M = 56.85, SD = 9.87). Women accounted for nearly 80% of the group. Majority of the subjects reported either secondary or higher education. Likewise, majority of the study participants were from small towns and rural areas (48.3% and 28.3%, respectively). Less than 50% of the subjects reported such medical conditions as hypertension, diabetes or obesity. The subjects affected by chronic diseases (M = 4.42, SD = 2.21) did not differ from those with no such problems (M = 4.09, SD = 1.99) in terms of the reported physical activity (t = 0.72, p = 0.47).

No associations were found between gender, type of occupation, or frequency of reported addictions and group composition (Table 1). In contrast, a correlation was shown between education level and group composition: each group predominantly comprised individuals with at least secondary education. The value of Cramer's V suggests that the relationship is weak. There was also a relationship between the self-reported health status and the group composition, at a level of statistical trend. The value of Cramer's V shows there is a weak association between the variables. The findings show that the groups were similar in terms of the individual and the demographic characteristics.

Consideration of quantitative variables showed no differences between the groups as regards the reported level of physical activity over the course of life, the number of words correctly produced in verbal fluency tests, as well as scores in BDI-II and Backward Digit Span test. Group 2 was significantly younger than Group 1. There were significant differences as regards other variables. Forward Digit Span test was most effectively performed by Group 3, which also achieved the poorest result in the Vocabulary subtest of WAIS-R PL. On the other hand the lowest scores in MoCA were identified in Group 1 participants who were also significantly less likely to complain about executive function (DEX-S).

Frequencies, means, standard deviations and comparative results are shown in Table 1.

4. Results

4.1. Group 1

Table 2 contains results of multivariate regression analyses for Group 1.

All the models (Table 2) were found to fit the data well. Age was the main predictor of performance in cognitive tasks: older age was conducive to lower scores. Furthermore, depression symptoms (BDI-II) and a sense of executive dysfunction in daily life (DEX-S) also increased with age. Age and self-reported physical activity jointly determined performance in three verbal fluency tasks, although the latter factor determined performance in these tests to a lesser extent than age. In this case, higher level of physical activity was positively associated with correct performance in these tests, whereas older age, like in the previous case, was conducive to poorer performance in verbal fluency tests.

4.2. Group 2

In these analyses (Table 3), a few models were found to fit the data well, and physical activity was shown to be the only determinant of performance in some tasks. Higher level of this type of activity corresponded to better scores in two verbal fluency tasks, better language efficiency (Vocabulary) and higher general cognitive capacities (MoCA). The variable of physical activity explains between 21% and 31% of the relationships between the variables.

4.3. Group 3

In the final study (Table 4), majority of the models were found to fit the data well. Age significantly determined the results obtained: higher age was conducive

Table 2. The determinants of test/task results: Multivariate Regression Analysis (enter method) (N = 120)

Variables	F (p)	R 2adj	Age (β)	Level of physical activity (β)
Semantic fluency	17.29*** (0,001)	0.21	- 0.43*** (0.001)	0.15* (0.05)
Verb fluency	14.89*** (0.001)	0.19	- 0.41*** (0.001)	0.14* (0.05)
Joy fluency	16.64*** (0.001)	0.21	- 0.39*** (0.001)	0.22** (0.008)
Fear fluency	7.67*** (0.001)	0.10	- 0.34*** (0.001)	0.004 (0.96)
Phonemic fluency	14.05*** (0.001)	0.18	- 0.44*** (0.001)	-0.07 (0.47)
Forward Digit Span	9.81*** (0.001)	0.13	- 0.34*** (0.001)	0.14 (0.12)
Backward Digit Span	11.89*** (0.001)	0.15	- 0.41*** (0.001)	-0.07 (0.41)
Vocabulary	17.67*** (0.001)	0.22	- 0.48*** (0.001)	0.02 (0.77)
MoCA (sum)	39.26*** (0.001)	0.39	- 0.64*** (0.001)	-0.03 (0.65)
BDI II	22.89*** (0.001)	0.27	0.53*** (0.001)	-0.009 (0.90)
DEX-S	6.40** (0.002)	0.08	0.32*** (0.001)	0.05 (0.54)

*p≤0.05; **p≤0.01; ***p≤0.001.

Table 3. The determinants of test/task results: Multivariate Regression Analysis (enter method) (N = 90)

Variables	F (p)	R 2adj	Age (β)	Level of physical activity (β)
BDI II	1.21 (0.30)			
DEX-S	0.44 (0.65)			
Semantic fluency	0.47 (0.63)			
Verb fluency	1.07 (0.35)			
Joy fluency	2.74* (0.05)	0.04	-0.08 (0.42)	0.23* (0.03)
Fear fluency	0.68 (0.51)			
Phonemic fluency	3.24* (0.04)	0.05	0.11 (0.29)	0.24* (0.02)
Forward Digit Span	0.82 (0.44)			
Backward Digit Span	1.78 (0.17)			
Vocabulary	2.52* (0.05)	0.03	0.11 (0.27)	0.21* (0.05)
MoCA (sum)	4.59* (0.02)	0.07	0.01 (0.92)	0.31** (0.003)

*p≤0.05; **p≤0.01.

Table 4. The determinants of test/task results: Multivariate Regression Analysis (enter method) (N = 60)

Variables	F (p)	R 2adj	Age (β)	Level of physical activity (β)
BDI II	3.57* (0.035)	0.08	0.04 (0.76)	-0.34** (0.01)
DEX-S	1.83 (0.17)			
Semantic fluency	6.65** (0.003)	0.16	-0.44*** (0.001)	0.07 (0.58)
Verb fluency	3.19* (0.049)	0.07	-0.32* (0.014)	0.07 (0.61)
Joy fluency	3.03* (0.044)	0.07	-0.25* (0.05)	-0.17 (0.19)
Fear fluency	2.45 (0.09)			
Phonemic fluency	1.33 (0.27)			
Forward Digit Span	5.98** (0.004)	0.15	-0.29* (0.02)	0.35** (0.005)
Backward Digit Span	12.74*** (0.001)	0.28	-0.42*** (0.001)	0.45*** (0.001)
Vocabulary	6.74** (0.002)	0.16	-0.44*** (0.001)	0.04 (0.72)
Moca (sum)	8.42*** (0.001)	0.20	-0.43*** (0.001)	0.29* (0.014)
TMT A (time/sec)	5.45** (0.007)	0.13	0.39** (0.002)	0.02 (0.89)
TMT B (time/sec	12.66*** (0.001)	0.28	0.54*** (0.001)	-0.26* (0.024)

*p≤0.05; **p≤0.01; ***p≤0.001.

to lower scores in cognitive tasks and longer time in TMT B task. On the other hand, higher levels of physical activity over the course of life corresponded to lower depression symptoms, longer sequences of digits reproduced forward and backward, better general cognitive capacities (MoCA), and shorter time needed to perform TMT B.

5. Discussion

While recapitulating the results of three independent studies involving a total of 270 adult Poles, the authors observed a general pattern: there is an age-related decline in performance in cognitive tasks, both those assessing general cognitive capacities (MoCA) and those involving memory, attention and executive processes, whereas greater self-reported levels of physical activity are conducive to better performance in cognitive tasks. This applies to tasks assessing executive functions (TMT B; verbal fluency), attention and short-term memory (Forward Digit Span), working memory (Backward Digit Span) or general cognitive capacity (MoCA). The current findings are consistent with earlier studies which have reported an age-related decline in the efficiency of certain cognitive functions (Oschwald et al., 2020), and positive effect of physical activity on executive functions, attention and overall cognitive functioning (Colcombe, Kramer 2003; Krivanek et al., 2021; Middleton et al., 2010; Pniewska et al., 2012), thereby demonstrating importance of regular physical activity introduced from an early age as an intervention to promote more effective cognitive functioning in late adulthood.

Engaging in physical activity during earlier stages of life positively affects the process of cognitive aging, because it contributes to development of brain and cognitive reserves. Brain reserve comprises structural characteristics of the CNS, such as the number of synapses or neurons, and functional features, i.e. the network of connections, which make it possible to maintain cognitive capacities despite the typical age-related pathological changes or disorders affecting the CNS (Stern et al., 2020). Longitudinal studies taking into account multiple risk factors for cardiovascular and neurodegenerative diseases (e.g., hypertension, lipid levels, diabetes, obesity, history of stroke, depression, nicotinism, APOE status and low education level) have shown that physical activity significantly reduces the risk of dementia (Cheng, 2016). The mechanism through which physical activity favourably affects cognitive functioning is based on various structural and functional processes of the CNS. It involves improvements in respiratory function, and cerebral perfusion, stimulation of brain-derived neurotrophic factor (BDNF), regulation of oxidative stress and inflammatory response processes, enhancement of neural network function (Boraxbekk, Salami, Wåhlin, Nyberg, 2016), as well as slowing of tau protein deposition (Krivanek et al., 2021). It produces structural changes in the region of the hippocampus (increase in proliferation and survival of cells and synapses in dentate gyrus), which are beneficial for learning and memory processes (Krivanek et al., 2021), as well as volumetric changes in the prefrontal cortex (Erickson, Gildengers, Butters, 2013) and parietal cortex (Castells-Sánchez et al., 2021), which are beneficial for executive functions. All of these have a protective effect on cognitive function, hence physical activity is an important element contributing to cognitive reserve, jointly with intellectual activity or social interactions. Physical activity also positively affects cognitive competences in an indirect way, owing to social interactions that accompany physical activity and by minimising negative emotionality (Castells-Sánchez et al., 2021; Krivanek et al., 2021). Moreover, physical activity as a factor stimulating cognitive capacities in late adulthood also plays an important role, for example, by preventing head injuries common in senior citizens and increasing independence in everyday life (Zhu, Li, Wang, Jin, Zhang, 2020).

The positive effect of physical activity on cognitive functioning observed in the current study was found to be significantly smaller than that of age. Both variables jointly explained a small percentage of the variance in the results, with the variable of physical activity explaining less than age. The correlational nature of the research in combination with the small percentage of variance explained by the factors taken into account suggests the possibility that both physical activity and cognitive status of older people may be significantly dependent on or related to other factors which support the aging process and were not included in this study.

It is also noteworthy that the results obtained in the three reported studies are not uniform, i.e. age, physical activity and the interaction of these variables do not always explain performance on the same tasks. It was only study 2 that systematically showed a positive relationship between physical activity level and the scores in the cognitive tasks, excluding the variable of age. Individuals in this group on average were younger and acquired the best results in Vocabulary subtest and in MoCa, compared to the remaining groups. The lack of the relationship between task performance and age in this youngest group may be linked to the fact that the group included people aged 40-45. The process of cognitive ageing is not linear; until around 50 years of age, the relationship between age and cognitive performance is not as strong as at the later stages, and deficits are evident from 60 years of age onwards (Oschwald et al., 2020). At the same time, the lack of differences between the groups in terms of the reported amount of physical activity may suggest that the same dose of physical activity produces different effects in cognitive functioning, depending on the age group. Younger individuals may benefit more from interventions involving physical activity; in their case age-related cognitive decline is much less severe and therefore does not significantly interfere with the positive effects of exercise on the body. On the other hand, the benefits of physical activity are also observed in older people (Hillman et al., 2006). Other studies show that exercise produces different effects in various cognitive domains in individuals representing different age groups. For example, Spartano and co-authors (2019) reported that in middle-aged individuals physical activity produced greater beneficial effects in verbal memory, whereas in older people better effects were observed in executive function. The latter findings are consistent with the results of the current study which showed that higher level of physical activity in Group 2, with the lowest mean age, was related to better performance in the task involving language competences and semantic memory (Vocabulary), whereas in the groups with higher mean age physical activity was related to performance in the tasks to a greater extent engaging executive functions (i.e. Group 1: verbal fluency, Group 3: Backward Digit Span and TMT B).

Another explanation for these results may be linked to the fact that older people are likely to misreport retrospective data, e.g. by overstating the reported level of physical activity. Although self-reported measures are commonly used, they generally present a risk of response distortion. Precision of self-reports on engaging in physical activity earlier in life may be affected not only by the respondent's age (Andrews, Herzog, 1986; Bielak, 2010), but also by his/her cognitive status (Knäuper, Belli, Hill, Herzog, 1997). In the current study, the findings showed the lowest association between physical activity and cognitive performance in Group 1, which comprised individuals with the highest mean age and the lowest level of general cognitive capacities, despite the fact that the reported level of physical activity was similar to that in the other groups. It cannot be ruled out that the observed weak relationship between physical activity and cognitive performance in this group of subjects is an effect of the self-report method applied to acquire the data used as an indicator of physical activity. To perform in-depth analysis and explore the possible explanations for the observed effects, it would be worthwhile to conduct research investigating the effects of physical activity on cognitive functioning in different age groups in a randomised controlled trial (RTC) model, with the additional use of objective indicators (i.e., pedometer or accelerometer).

Finally, two variables seem to be of interest, i.e. gender and formal education of the participants, since these may be relevant to the findings. All the groups predominantly comprised females and individuals with at least secondary formal education. Various research reports suggest that girls/women are less likely to engage in physical activity in unstructured settings (e.g. during leisure time) in favour of activity during daily routines (Ransdell, Vener, Sell, 2004). This, in particular, may apply to the females participating in our study who were born before and during the period of Poland's political transition. Irrespective of gender, participation in physical activities is most common in children and adolescents, and it decreases in early adulthood (Schulze et al., 2020).

Low level of physical activity is observed particularly in individuals aged 55+ (Notthoff, Reisch, Gerstorf, 2017). In turn, a higher level of education is linked with greater awareness of health-promoting effects of physical activity, and with a greater likelihood of taking up occupations which contribute to one's cognitive competences but are also frequently associated with sedentary work (Shaw, Spokane, 2008). By contrast, lower level of formal education is conducive to engaging in physical work, linked with greater likelihood of deteriorating health and lower tendency to engage in additional activities. Hence, further research focusing on cognitive capacities in late life should take into account the factors of gender and education in relation to physical activity.

Conclusions

1. Self-reported higher level of physical activity over the course of life positively impacts cognitive performance at old age.
2. While age promotes cognitive decline, physical activity can play a compensatory role and support cognitive competences, especially those related to executive functions.
3. Physical activity rather than age was the main determinant of cognitive performance in the youngest participants, i.e. those aged 45-60 years. This may suggest that the relationship between this type of activity and cognitive capacities may depend on the subjects' age.

Bibliography

Andrews, F.M., & Herzog, A.R. (1986). The quality of survey data as related to age of respondent. *Journal of the American Statistical Association*, *81(394),* 403–410. https://doi.org/10.2307/2289229

Aunger, J, & Wagnild, J. (2020). Objective and subjective measurement of sedentary behavior in human adults: A toolkit. *American Journal of Human Biology*, e23546. https://doi.org/10.1002/ajhb.23546

Barnes, D.E., Yaffe, K., Satariano, W.A., & Tager, I.B. (2003). A longitudinal study of cardiorespiratory fitness and cognitive function in healthy older adults. *Journal of the American Geriatrics Society*, *51(4),* 459-465. https://doi.org/10.1046/j.1532-5415.2003.51153.x

Barnes, J.N. (2015). Exercise, cognitive function, and aging. *Advances in Physiology Education*, *39(2),* 55–62. https://doi.org/10.1152/advan.00101.2014

Bergier, B., Gawlik, K., Baj-Korpak,1., Stępień, E., Pocztarska-Głos, A., Sidor, M., & Szepeluk, A. (2020). Subjective and objective assessments of physical activity in employed women aged 50 to 64 years. *Central European Journal of Sport Sciences and Medicine*, *31(3),* 5–16. https://doi.org/10.18276/cej.2020.3-01

Bidzan-Bluma, I., & Lipowska, M. (2018). Physical activity and cognitive functioning of children: a systematic review. *International Journal of Environmental Research and Public Health, 15(4),* 800. https://doi.org/10.3390/ijerph15040800

Bielak, A.A.M. (2010). How can we not 'lose it' if we still don't understand how to 'use it'? Unanswered questions about the influence of activity participation on cognitive performance in older age–a mini-review. *Gerontology*, *56*(5), 507-519. https://doi.org/10.1159/000264918

Blondell, S.J., Hammersley-Mather, R. & Veerman, J.L. (2014). Does physical activity prevent cognitive decline and dementia?: A systematic review and meta-analysis of longitudinal studies. *BMC Public Health*, *14*, 510. https://doi.org/10.1186/1471-2458-14-510

Booth, M.L. (2000). Assessment of physical activity: an international perspective. *Research Quarterly for Exercise and Sport*, *71*(2), 114-120. https://doi.org/10.1080/02701367.2000.11082794

Boraxbekk, C., Salami, A., Wåhlin, A., & Nyberg, L. (2016). Physical activity over a decade modifies age-related decline in perfusion, gray matter volume, and functional connectivity of the posterior default-mode network-a multimodal approach. *Neuroimage, 131,* 133–141. https://doi.org/10.1016/j.neuroimage.2015.12.010

Brzeziński, J., Gaul, M., Hornowska, E., Jaworowska, A., Machowski, A., & Zakrzewska, M. (2004). *Skala Inteligencji D. Wechslera dla Dorosłych. Wersja Zrewidowana–Renormalizacja. WAIS-R (PL). Podręcznik.* [D. Wechsler's Intelligence Scale for Adults. Revised Version–Renormalization. WAIS-R (PL)]. Warszawa: Pracownia Testów Psychologicznych Polskiego Towarzystwa Psychologicznego.

Bull, F., Maslin, T., Armstrong, T. (2009). Global Physical Activity Questionnaire (GPAQ): nine country reliability and validity study. *Journal of Physical Activity and Health*, *6*, 790-804. https://doi.org/10.1123/jpah.6.6.790

Busse, A., Gil, G., Santarém, J., & Filho, W. (2009). Physical activity and cognition in the elderly. A review. *Dementia & Neuropsychologia*, *3*(3), 204-208. https://doi.org/10.1590/S1980-57642009DN30300005

Castells-Sánchez, A., Roig-Coll, F., Dacosta-Aguayo, R., Lamonja-Vicente, N., Sawicka, A., Torán-Monserrat, P., Pera, G., Montero-Alía, P., Heras-Tebar, A., Domènech, S., Via, M., Erickson, K., & Mataró, M. (2021). Exercise and fitness neuroprotective effects: molecular, brain volume and psychological correlates and their mediating role in healthy late-middle-aged women and men. *Frontiers in Aging Neuroscience*, *13*, 80. https://doi.org/10.3389/fnagi.2021.615247

Cheng, S.T. (2016). Cognitive reserve and the prevention of dementia: the role of physical and cognitive activities. *Currents in Psychiatry Report*, *18*, 85. https://doi.org/10.1007/s11920-016-0721-2

Colcombe, S., & Kramer, A.F. (2003). Fitness effects on the cognitive function of older adults: a meta-analytic study. *Psychological Sciences*, *14*(2), 125-130. https://doi.org/10.1111/1467-9280.t01-1-01430

Dik, M., Deeg, D.J., Visser, M., & Jonker, C. (2003). Early life physical activity and cognition at old age. *Journal of Clinical and Experimental Neuropsychology*, *25*(5), 643-653. https://doi.org/10.1076/jcen.25.5.643.14583

Erickson, K., Gildengers, A., & Butters, M. (2013). Physical activity and brain plasticity in late adulthood. *Dialogues in Clinical Neuroscience*, *15*, 99-108. https://doi.org/10.31887/DCNS.2013.15.1/kerickson

Finger, J.D., Gisle, L., Mimilidis, H., Santos-Hoevener, C., Kruusmaa, E.K., Matsi, A., Oja, L., Balarajan, M., Gray, M., Kratz, A.L., & Lange, C. (2015). How well do physical activity questions perform? A European cognitive testing study. *Archives of Public Health; 73*, 57. https://doi.org/10.1186/s13690-015-0109-5

de Greeff, J.W., Bosker, R.J., Oosterlaan, J., Visscher, C., & Hartman, E. (2018). Effects of physical activity on executive functions, attention and academic performance in preadolescent children: a meta-analysis. *Journal of Science and Medicine in Sport, 21*(5), 501-507. https://doi.org/10.1016/j.jsams.2017.09.595

Green, Ch., Lee, H., & Thuret, S. (2019). In the Long Run: physical activity in early life and cognitive aging. *Frontiers in Neuroscience,* https://doi.org/10.3389/fnins.2019.00884

Guure, C.B., Ibrahim, N.A., Adam, M.B., & Said, S.M. (2017). Impact of physical activity on cognitive decline, dementia, and its subtypes: meta-analysis of prospective studies. *BioMed Research International*, 1-13. https://doi.org/10.1155/2017/9016924

Hamer, M., & Chida, Y. (2009). Physical activity and risk of neurodegenerative disease: A systematic review of prospective evidence. *Psychological Medicine*, *39*, 3–11. https://doi.org/10.1017/S0033291708003681

Hillman, C.H., Motl, R.W., Pontifex, M.B., Posthuma, D., Stubbe, J.H., Boomsma, D.I.,& de Geus, E.J.C. (2006). Physical activity and cognitive function in a cross-section of younger and older community-dwelling individuals. *Health Psychology, 25(*6), 678-687. https://doi.org/10.1037/0278-6133.25.6.678

Hoang, T.D., Reis, J., Zhu, N., Jacobs, D.R. Jr, Launer, L.J., Whitmer, R.A., Sidney, S., & Yaffe, K. (2016). Effect of early adult patterns of physical activity and television viewing on midlife cognitive function*. JAMA Psychiatry*, *73*(1), 73-79. https://doi.org/10.1001/jamapsychiatry.2015.2468

Ingold, M., Tulliani, N., Chan, Ch., & Liu, K. (2020). Cognitive function of older adults engaging in physical activity. *BMC Geriatrics*, *20*, 229. https://doi.org/10.1186/s12877-020-01620-w

Innerd, P., Catt, M., Collerton, J., Davies, K., Trenell, M., Kirkwood, T., & Jagger, C. (2015). A comparison of subjective and objective measure of physical activity from the Newcastle 85+ study. *Age and Ageing*, *44,* 691-694. https://doi.org/10.1093/ageing/afv062

Klimova, B., & Dostalova, R. (2020). The impact of physical activities on cognitive performance among healthy older individuals. *Brain Sciences*, *10*, 377. https://doi.org/10.3390/brainsci10060377

Knäuper, B., Belli, R.F., Hill, D.H., & Herzog, A.R. (1997). Question difficulty and respondents' cognitive ability: the impact on data quality. *Journal of Official Statistics*, *13*(2)*,* 181–199.

Krivanek, T., Gale, S., McFeeley, B., Nicastri, C., & Daffner, K. (2021). Promoting successful cognitive aging: a ten-year update. *Journal of Alzheimer's Disease*, *81*, 871–920. https://doi.org/10.3233/JAD-201462

Lezak, M., Howieson, D., Bigler, E., & Tranel, D. (2012). *Neuropsychological Assessment*. 5ed. Oxford: Oxford University Press.

Łojek, E., & Stańczak, J. (2019). *BDI-II – Inwentarz Depresji Becka – wydanie drugie* [BDI-II–Beck Depression Inventory]. Warszawa: Pracownia Testów Psychologicznych Polskiego Towarzystwa Psychologicznego.

Middleton, L.E., Barnes, D.E., Lui, L.Y., & Yaffe, K. (2010). Physical activity over the life course and its association with cognitive performance and impairment in old age. *Journal of American Geriatrics Society*, *58*(7), 1322-1326. https://doi.org/10.1111/j.1532-5415.2010.02903.x

Nasreddine, Z.S., Phillips, N.A., Bédirian, V., Charbonneau, S., Whitehead, V., Collin, I., Cummings, J.L., & Chertkow, H. (2005). The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. *Journal of American Geriatrics Society*, *53*(4), 695-699. https://doi.org/10.1111/j.1532-5415.2005.53221.x

Notthoff, N., Reisch, P., & Gerstorf, D. (2017). Individual Characteristics and Physical Activity in Older Adults: A Systematic Review. *Gerontology, 63*, 443–459. https://doi.org/10.1159/000475558

Oschwald, J., Guye, S., Liem, F., Rast, Ph., Willis, S., Röcke, Ch., Jäncke, L., Martin, M., & Mérillat, S. (2020). Brain structure and cognitive ability in healthy aging: a review on longitudinal correlated change. *Reviews in the Neurosciences*, *31*(1), 1–57. https://doi.org/10.1515/revneuro-2018-0096

Panza, G.A., Taylor, B.A., Thompson, P.D., White, C.M., & Pescatello, L.S. (2019). Physical activity intensity and subjective well-being in healthy adults. *Journal of Health Psychology*, *24*(9)*,* 1257-1267. https://doi.org/10.1177/1359105317691589

Pniewska, J., Jaracz, K., Górna, K., Czajkowska, A., Liczbińska, G., Łojko, D., Pałys, W., & Suwalska, A. (2012). Styl życia a funkcjonowanie poznawcze osób starszych. Doniesienia wstępne [Lifestyle and cognitive functioning of the elderly. Preliminary reports]. *Nowiny Lekarskie, 81*(1), 10-15.

Ransdell, L.B., Vener, J.M., & Sell, K. (2004). International perspectives: the influence of gender on lifetime physical activity participation. *Journal of the Royal Society for the Promotion of Health, 124*(1),12-14. https://doi.org/10.1177/146642400312400105

Reas, E.T., Laughlin, G.A., Bergstrom, J., Kritz-Silverstein, D., Richard, E.L., Barrett-Connor, E., & McEvoy, L.K. (2019). Lifetime physical activity and late-life cognitive function: the Rancho Bernardo study. *Age and ageing*, *48*(2), 241–246. https://doi.org/10.1093/ageing/afy188

Richards, M., Hardy, R., & Wadsworth, M.E. (2003). Does active leisure protect cognition? Evidence from a national birth cohort. *Social Science & Medicine*, *56*(4), 785-792. https://doi.org/10.1016/s0277-9536(02)00075-8

Rovio, S., Kåreholt, I., Helkala, E.L., Viitanen, M., Winblad, B., Tuomilehto, J,. Soininen, H., Nissinen, A., & Kivipelto, M. (2005). Leisure-time physical activity at midlife and the risk of dementia and Alzheimer's disease. *Lancet Neurology*, *4*(11), 705-711. https://doi.org/10.1016/S1474-4422(05)70198-8

Schulze, C., Demetriou, Y., Emmerling, S., Schlund, A., Phillips, S., Puil, L., Coen, S., & Reimers, A. (2020). A sex/gender perspective on interventions to promote children's and adolescents' overall physical activity: results from genEffects systematic review. *BMC Pediatrics, 20*, 473. https://doi.org/10.1186/s12887-020-02370-9

Shaw, B.A., & Spokane, L.S. (2008). Examining the association between education level and physical activity changes during early old age. *Journal of Aging and Health*, *20*(7), 767–787. https://doi.org/10.1177/0898264308321081

Singh, A.S., Saliasi, E., van den Berg, V., Uijtdewilligen, L., de Groot, R.H., Jolles, J., Andersen, L.B., Bailey, R., Chang, Y.K., Diamond, A., Ericsson, I., Etnier, J.L., Fedewa, A.L., Hillman, C.H., McMorris, T., Pesce, C., Pühse, U., Tomporowski, P.D., & Chinapaw, M.J. (2019). Effects of physical activity interventions on cognitive and academic performance in children and adolescents: a novel combination of a systematic review and recommendations from an expert panel. *British Journal of Sports and Medicine, 53*(10), 640-647. https://doi.org/10.1136/bjsports-2017-098136

Sofi, F., Valecchi, D., Bacci, D., Abbate, R., Gensini, G.F., Casini, A., & Macchi, C. (2011). Physical activity and risk of cognitive decline: A meta-analysis of prospective studies. *Journal of Internal Medicine*, *269*(1), 107-117. https://doi.org/10.1111/j.1365-2796.2010.02281.x

Spartano, N.L., Demissie, S., Himali, J.J., Dukes, K.A., Murabito, J.M., Vasan, R.S., Beiser, A.S., & Seshadri, S. (2019). Accelerometer-determined physical activity and cognitive function in middle-aged and older adults from two generations of the Framingham Heart Study. *Alzheimer's & Dementia, 5*, 618-626. https://doi.org/10.1016/j.trci.2019.08.007

Stern, Y., Arenaza-Urquijo, E.M., Bartres-Faz, D., Belleville, S., ´Cantilon, M, Chetelat, G., Ewers, M., Franzmeier, N., Kempermann, G., Kremen, W.S., Okonkwo, O., Scarmeas, N., Soldan, A, Udeh-Momoh, C., Valenzuela, M., Vemuri, P., & Vuoksimaa, E. (2020). Whitepaper: Defining and investigating cognitive reserve, brain reserve, and brain maintenance. *Alzheimer's and Dementia*, *16*, 1305-1311. https://doi.org/10.1016/j.jalz.2018.07.219

Szepietowska, E.M., & Gawda, B. (2011). *Ścieżkami fluencji słownej* [Paths of verbal fluency]. Lublin: Wydawnictwo UMCS.

Wasilewska, M. (2017). In search of the assessment of the physical activity level of the youth with the use of the IPAQ. *Health Problems of Civilisation, 11,* 15-22, https://doi.org/10.5114/hpc.2017.65524

Wilson, B.A., Alderman, N., Burgess, P.W., Emslie, H., & Evans, J.J. (1996). *Behavioural assessment of the dysexecutive syndrome (BADS)*. London: Thames Valley Test Company.

Yaffe, K., Barnes, D., Nevitt, M., Lui, L.Y., & Covinsky, K. (2001). A prospective study of physical activity and cognitive decline in elderly women: women who walk. *Archives of Internal Medicine*, *161*(14), 1703-1708. https://doi.org/10.1001/archinte.161.14.1703

Zhu, N., Jacobs, D.R., Jr, Schreiner, P.J., Yaffe, K., Bryan, N., Launer, L.J., Whitmer, R.A., Sidney, S., Demerath, E., Thomas, W., Bouchard, C., He, K., Reis, J., & Sternfeld, B. (2014). Cardiorespiratory fitness and cognitive function in middle age: the CARDIA study. *Neurology*, *82*(15), 1339–1346. https://doi.org/10.1212/WNL.0000000000000310

Zhu, L., Li, L., Wang, L., Jin, X., & Zhang, H. (2020). Physical activity for executive function and activities of daily living in ad patients: a systematic review and meta-analysis. *Frontiers in Psychology*, *11*, 560461. https://doi.org/10.3389/fpsyg.2020.560461